Report for 2015–2016 from the Bordeaux IVS Analysis Center

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Abstract This report summarizes the activities of the Bordeaux IVS Analysis Center in 2015 and 2016. The work in that period was focused primarily on (i) the regular analysis of the IVS-R1 and IVS-R4 sessions with the GINS software package; (ii) the systematic VLBI imaging of the RDV sessions and calculation of the corresponding source structure index and compactness values, and (iii) the involvement in the IAU Working Group on the next ICRF (International Celestial Reference Frame) realization. The latter is concerned with the assessment of source quality and the identification of transfer sources for the alignment between the ICRF and the future Gaia optical frame. Since summer 2015, a member of the Bordeaux group also has chaired the Working Group. Apart from these activities, the year 2016 was also marked by the move from the historical site of the *Observatoire de Bordeaux* to new premises on the campus of the University of Bordeaux.

1 General Information

The *Laboratoire d'Astrophysique de Bordeaux (LAB)* is a research center which is funded by the University of Bordeaux and the *Centre National de la Recherche Scientifique (CNRS)*. It is part of a bigger institute, the *Observatoire Aquitain des Sciences de l'Univers (OASU)*, formerly Bordeaux Observatory. The OASU has a wider scope, covering environmental sciences besides historic activities in astronomy and astrophysics. A specific role of the observatory is to provide support for acquiring, analyzing, and archiving observations of various types in these fields, including participation in national and international services, such as the IVS.

Fig. 1 The new OASU building that has hosted the LAB and the Bordeaux IVS Analysis Center on the Campus of the University of Bordeaux in Pessac since June 2016.

A major event happened in the spring of 2016 with the relocation of the 130-year old observatory from its historical site in Floirac [1] to its new premises $\sim$ 15 km away on the campus of the University of Bordeaux in Pessac, where a dedicated building was constructed for the OASU (Figure 1). The new premises offer individual offices, purpose-built laboratories (electronics, mechanics, etc.), and modern conference rooms (ready for videoconferencing). The new address is the following:

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Bordeaux Analysis Center

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VLBI activities within the LAB are primarily developed within the M2A team (*Métrologie de l'espace, Astrodynamique, Astrophysique*). The contribution of the group to IVS has been mostly concerned with the maintenance, extension, and improvement of the International Celestial Reference Frame (ICRF). This includes regular imaging of the ICRF sources and evaluation of their astrometric suitability, as well as developing specific VLBI observing programs for enhancing the celestial frame. In addition, the group is in charge of the VLBI component of the GINS software package, a multi-technique software developed by the CNES (*Centre National d'Etudes Spatiales*) which has the ability to process data from most space geodetic techniques, including GNSS, VLBI, DORIS, SLR, LLR, satellite altimetry, and other space missions [2].

2 Description of Analysis Center

The Bordeaux IVS group routinely analyzes the IVS-R1 and IVS-R4 sessions with the GINS software package. From these sessions, weekly solutions estimating EOPs with six-hour resolution are produced. Until 2015, the primary objective of such analyses was the integration of the corresponding VLBI data into multi-technique solutions combining VLBI and other space geodetic data (SLR, GPS, and DORIS) at the observation level through a collaborative effort within the French *Groupe de Recherches de Géodésie Spatiale (GRGS)*, as noted in previous reports. With the termination of this activity, the focus is now placed upon developing an operational VLBI analysis with the goal of contributing to the rapid IVS primary EOP combination.

The group is also focused on imaging the ICRF sources on a regular basis by systematic analysis of the data from the RDV sessions, which are conducted six times a year. This analysis is carried out with the AIPS and DIFMAP software packages. The aim of such regular imaging is to characterize the astrometric suitability of the sources based on the so-called "structure index" and to compare source structural evolution and positional instabilities. Such studies are essential for identifying sources of high astrometric quality, which is required, e.g. for the construction of ICRF3 or for selecting proper sources for aligning the Gaia frame.

3 Scientific Staff

During 2015 and 2016, six individuals contributed to one or more of our IVS analysis and research activities. A description of what each person worked on, along with the time spent on it, is given below. It is to be noted that Romuald Bouffet defended his Ph. D. thesis on 16 June 2015 [3]. He then left the field and now works for industry. Apart from this change, there were no other changes in the IVS staff over the period.

- Patrick Charlot (30%): researcher with overall responsibility for Analysis Center work and data processing. His interests include the ICRF densification, extension, and link to the Gaia frame, studies of radio source structure effects in astrometric VLBI data, and astrophysical interpretation. He has also been Chair of the IAU Working Group on the next ICRF realization since August 2015.
- Antoine Bellanger (100%): engineer with a background in statistics and computer science. He is tasked to process VLBI data with GINS and to develop procedures and analysis tools to automate such processing with prospects of implementing an operational VLBI analysis in the future.
- Romuald Bouffet (30%, until June 2015): Ph. D. student from the University of Bordeaux whose thesis was focused on the study of the relationship between radio source structure and position instabilities. His work was largely based on astrometric data and VLBI images derived from IVS sessions.
- Géraldine Bourda (50%): astronomer in charge of developing the VLBI part of GINS and responsible for the analysis results derived from GINS. She also leads a VLBI observational program for linking the ICRF and the future Gaia optical frame.
- Arnaud Collioud (90%): engineer with a background in astronomy and interferometry. His tasks are to image the sources in the RDV sessions using AIPS and DIFMAP, to develop the Bordeaux VLBI Image Database and *IVS Live* tool, and to conduct simulations for the next generation VLBI system.
- Alain Baudry (10%): radioastronomy expert with specific interest in radio source imaging and astrometric VLBI. He is a Professor Emeritus and is working part time as a co-investigator for developing upgrades of the ALMA mm/submm array.

4 Current Status

As noted above, one of our goals for the future is to implement an operational analysis of the IVS-R1 and IVS-R4 sessions for EOP determination using the GINS software package. To reach this goal, a prerequisite is to assess the quality of the results derived with GINS and to validate these against similar determinations obtained with other VLBI software packages, because GINS, in its VLBI capability, is not used by any other groups. To this aim, we joined the VLBI Analysis Software Comparison Campaign initiated by Chalmers University of Technology in the fall of 2015, the results of which were presented at the IVS 2016 General Meeting [4]. The comparison, however, turned out to be not fully conclusive for GINS. We were not sure that the total delay model, which was compared, was exactly identical in all of its components that were implemented in other VLBI software packages. A second stage, which compares the individual components of the delay model separately, is thus to be carried out.

Another major part of our activity consists of systematic imaging of the sources observed during the RDV sessions. During 2015 and 2016, eight such sessions were processed (from RDV96 to RDV110), resulting in 1,303 VLBI images at either X- or S-band for 415 different sources. The imaging work load has been shared with USNO since 2007 (starting with RDV61); the USNO group processes the odd-numbered RDV sessions while the Bordeaux group processes the even-numbered ones. The VLBI images are used in a second stage to derive structure correction maps and visibility maps along with values for structure indices and source compactness in order to assess astrometric source quality (see [5, 6] for a definition of these quantities). All such information is made available through the Bordeaux VLBI Image Database (BVID)[1]. At present, the BVID comprises a total of 5,179 VLBI images for 1,273 different sources (with links to an additional 6,775 VLBI images from the Radio Reference Frame Image Database of USNO), along with 11,744 structure correction maps and as many visibility maps.

Preparatory work for the realization of ICRF3 is an additional activity that gained increasing importance over the past two years. Two members of the group (Géraldine Bourda and Patrick Charlot) are members of the IAU Working Group on the next ICRF realization and as such contribute to the effort towards ICRF3. Their contribution has to do with (i) the assessment of astrometric source quality, a primary criterion to select ICRF3 defining sources, and (ii) the identification of proper transfer sources for the alignment of the future Gaia frame. Additionally, Patrick Charlot took over as Chair of the Working Group for the term 2015–2018, following appointment at the last IAU General Assembly in August 2015. In all, four face-to-face meetings of the Working Group were organized in 2015–2016 (Ponta Delgada, Azores, 21 May 2015; Honolulu, Hawaii, 6 August 2015; Ekudeni, South Africa, 16 March 2016, and Haystack, USA, 17-18 October 2016) along with three teleconferences in 2016, all of which were attended by at least one member from Bordeaux. Patrick Charlot also gave invited presentations about the progress on ICRF3 at the IVS 2016 General Meeting (Ekudeni, 13-17 March 2016), at a French workshop about fundamental physics and reference systems (Paris, 2-3 June 2016), and at the 13th EVN Symposium (St. Petersburg, Russia, 20-23 September 2016). The coming 1.5 years promise to be exciting, with ICRF3 to be completed by early 2018, for an adoption during the next IAU General Assembly in August 2018.

5 Dissemination and Outreach

The *IVS Live* Web site[2], a specific tool developed by the Bordeaux group, provides "Live" information about ongoing IVS sessions, including VLBI images of the observed sources [7]. The Web site is updated automatically based on the IVS Master Schedule. At the end of 2016, 7,617 IVS sessions were available, featuring 2,118 sources, with 74 stations involved. Tracing the connections indicates that there were 1,331 visits (from 61 countries) in 2015 and 2,197 visits (from 86 countries) in 2016. This is similar to the statistics of access to BVID, which show 915 visits (from 60 countries) in 2015 and 1,200 visits (from 79 countries) in 2016. As for dissemination, also to be mentioned is a presentation about VGOS by Patrick Charlot at a French workshop on millimeter geodesy [8].

[1] The Bordeaux VLBI Image Database may be accessed at http://astrophy.u-bordeaux.fr/BVID.

[2] The IVS Live Web site may be accessed at http://ivslive.obs.u-bordeaux1.fr.

6 Future Plans

Our plans for the next two years will be focused at first on implementing an operational analysis of the IVS-R1 and IVS-R4 sessions with the GINS software package. This implies validating the quality of the results derived with GINS, hence requiring further comparisons with other VLBI software packages, and demonstrating that we can sustain such operations in the long-term. Imaging the RDV sessions and evaluating the astrometric suitability of the sources, a specificity of the Bordeaux group, will be continued along the same lines. Of importance for the dissemination of the corresponding products is the reshaping of BVID with a new graphical interface and more functionalities, which is planned in the short term. The realization of the ICRF3 and its adoption by the IAU at the next General Assembly in the summer of 2018 will be crucial for the community. Our contributions to this effort lie mostly with the evaluation of the astrometric suitability of the sources, a task that is essential for selecting defining sources, and with the identification of proper Gaia transfer sources through dedicated observing programs or based on existing IVS data. Finalization of the list of such proposed Gaia transfer sources should be accomplished shortly. Organizing the overall work through face-to-face meetings and teleconferences falls to the Chair of the Working Group, who is a member of the Bordeaux group. Dissemination will include presenting ICRF3 at various meetings, preparing documentation and IAU resolutions, and writing a referred paper.

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